SP226 **Thermal Expansion** Spring 2000

Purpose: To measure the coefficient of linear expansion for copper, aluminum, and steel from about 20 ˚C to about 100 ˚C and compare the results to other measured values.

Method: You can measure the coefficient of linear expansion of a homogeneous material by making a rod of that material and measuring its length at two different temperatures. Then you can calculate the coefficient of linear expansion from the definition:

$$\alpha = \frac{\Delta L / L}{\Delta T}. \qquad \text{(eq. 1)}$$

Here L is the length of the rod, ΔL is the change in length, and ΔT is the temperature change over which ΔL occurs.

In today's experiment, you will use the Pasco Model TD-8558 Thermal Expansion apparatus to help you make the measurements. This apparatus consists of a set of expansion samples in the form of long hollow tubes, a steam generator to heat the samples, a base to hold the samples while you heat them, and devices to measure their length and temperature.

You can measure L reasonably well with a meter stick; but, because ΔL is much smaller than L, you will need a different instrument to measure it. You will use a mechanical dial gauge that can measure motions of its "spring arm" that are as small as 0.01 mm. The body of the gauge is fixed to the base of the thermal expansion apparatus and the end of the spring arm presses against a bracket that is bolted near one end of the sample. As the sample expands, the bracket moves, and the dial gauge measures that motion.

You will measure the sample temperature using a thermistor. A thermistor is a ceramic semiconductor whose resistance changes with temperature. You will use an ohmmeter to measure its resistance. A "negative temperature coefficient" (NTC) thermistor, the kind you will be using today, has a high resistance at low temperatures and a low resistance at high temperatures. The variation of resistance with temperature is nonlinear, so you will use a calibration table to convert measured resistances to temperatures.

Reference: Tipler, Chapter 21, Section 1, pp. 663-637.

Procedure:

1. Look over your apparatus.

Examine the copper, aluminum, and steel expansion tubes. Figure out which is which. Observe how the expansion tubes fit into the brackets at the ends of the base and how the thermistor attaches at the center of each tube. Notice, too, how the dial gauge measures the position of the bracket bolted near one end of the tube.

2. Measure the original length and temperature of the copper tube.

Use a meter stick to measure the length, L, of the copper sample tube at its initial temperature, T_i, which should be very near room temperature. Measure from the inner edge of the stainless steel pin at one end of the tube to the inner edge of the angle bracket at the other end. Record your value of L with an estimate of its uncertainty.

Mount the sample tube into the base of the apparatus. The stainless steel pin on the tube fits into the slot on the slotted mounting block, and the bracket on the tube presses against the spring arm of the dial gauge. Be careful not to damage the dial gauge when you insert the tube: gently pull back on the spring arm to make room for the bracket.

Attach the thermistor mounting lug to the threaded stud in the middle of the tube. Align the lug with the tube axis so it makes good thermal contact with the tube. Place the foam insulator over the thermistor lug to help insure that the thermistor is at the same temperature as the tube.

Turn on the ohmmeter and read the thermistor's resistance. Wait until the resistance stops changing (or changes only very slowly). Then the thermistor will be at the same temperature as the tube. Record the resistance R_i and use the thermistor calibration table printed on the base to find the initial temperature T_i. Interpolate as needed between the two closest table values and estimate your uncertainty in T_i.

3. Heat the tube and measure its new length and temperature.

Connect the sample tube to the steam generator with a flexible hose. Connect another flexible hose to the far end of the tube, and direct that hose into the sink. Use a small block to raise one end of the base by a few centimeters so that any water that condenses in the sample tube can drain into the sink.

Turn the outer casing of the dial gauge so that the indicator needle points to zero on the circular scale. This will help you read ΔL more conveniently. Observe the smaller, "turns-counting" scale, and make note of the position of its small pointer. This will help you in case the indicator needle "wraps around" as the tube expands.

Be sure there's water in the steam generator and then light the Bunsen burner under it. As you heat the tube, read the ohmmeter and the dial gauge every minute or so, to be sure you know when things start changing. Wait until the ohmmeter reading stabilizes, and then record the final resistance R_f and the final position of the dial gauge. Turn off the Bunsen burner after you've recorded these values so the tube can start cooling.

Use the thermistor's calibration table to find T_f and its uncertainty. Calculate ΔT and its uncertainty. Use the change in the reading of the dial gauge to find the change ΔL in the length of the sample tube. Notice that each small division on the dial gauge represents a change of 0.01 mm in the position of the end of the spring arm. Estimate the uncertainty in ΔL.

4. Calculate the coefficient of linear expansion for copper.

Use your measured values of L, ΔL, and ΔT to find the coefficient of linear expansion α.. Estimate the uncertainty in α..

5. Repeat these procedures and calculations using the aluminum and steel expansion tubes.

Be careful when you disconnect the flexible hoses and when you handle the hot expansion tubes. Make sure the steam generator is turned off before disconnecting the hoses, and direct their open ends away from yourself and others. Use the foam insulator to pick up the hot sample tubes so you don't burn your hands.

Conclusions:

Compare your measured values of α. for copper, aluminum, and steel with values someone else has obtained. Start by looking in your textbook: compare your values with the corresponding ones in Tipler, shown to the right, and state whether they are consistent within the uncertainties of your measurements. Next, consult with one or (better) several other lab groups. Identify the groups, list their values, and make a formal comparison of your results with theirs. Include uncertainties: use the average and the standard deviation of the values from other lab groups as the best estimate of their measured coefficient and its uncertainty.

Report:

For each material, make a table containing R_i, T_i, L, R_f, T_f, ΔT and ΔL together with their uncertainties. Show your calculation of α and its uncertainty. Show your comparison of α with Tipler's and with your classmates' as described above.